SELF-HEALING DIELECTRICS

Lighting up soft robotics

A transparent, high permittivity elastomeric dielectric material shows potential for light-emitting soft robots and stretchable optoelectronics that can self-heal.

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The development of non-silicon flexible electronics has been a growing target for scientists and engineering. This has accelerated since the awarding of the chemistry Nobel prizes to Heeger, MacDiarmid, and Shirakawa for the discovery of electrically conductive polymers at the turn of the century. Building on their and others' seminal works, optoelectronic devices including organic light emitting diodes (OLEDs) and electroluminescent (EL) devices have been developed and are being commercialised in the latest flexible (but notably, not stretchable) light sources and screens. Simultaneously, as the field of flexible optoelectronics has matured, the complementary field of soft robotics has emerged [1]. Soft robotics exploits smart compliant materials to make robots as well as wearable and medical devices that are stretchable, conform to our bodies and which can operate in extreme environments. Writing in Nature Materials, Yu Jun Tan and colleagues bring together the fields of flexible optoelectronics and soft robotics, showing a high-permittivity elastomer that is light-emitting, stretchable and self-healing [2]. This adds new capabilities in the form of stretchable displays and self-healing soft robots.

Researchers working on compliant electroluminescence are faced with two challenges. First, they need to increase the light output of electroluminescent materials while significantly reducing the driving voltage and frequency; second, they must achieve this in a material that could be stretched, twisted and radially deformed. In seeking to overcome these challenges, Tan and colleagues have developed a high dielectric elastomer material based on poly(vinylidene fluoride) (PVDF) modified by the addition of a non-ionic fluorinated surfactant. While it has been known for some time that the addition of ionic plasticisers to PVDF-based materials will increase their compliance, these ionic species render the materials unusable for use in light emitting capacitors (LEC devices) exploiting the electroluminescence principle. Alternatively, non-ionic plasticisers such as dibutyl phthalate may be used, but these have modest effects on the dielectric constant of the PVDF. However, by using a non-ionic surfactant, Tan and co-workers have produced a material that is not only suitable for use in LEC devices but has high permittivity and is transparent and highly stretchable. They show that the material can be stretched up to eight times its original length without breaking. The team also discovered that the material can self-heal: when cut the material can re-bond to itself without any extra processing or adhesive materials. This is an extremely attractive property for soft robots that may undergo damage during remote operation and be far from a repair facility.

The team use their high-permittivity elastomer material to form a three-layer LEC device which they term the Healable, Low-field Illuminance Optoelectronic and Stretchable (HELIOS) optoelectronic device (Fig.1a). In this thin laminar structure, the elastomer is used to realize both two conducting electrode layers, with the addition of an ionic liquid, and the emitting layer sandwiched between the electrodes, this time adding phosphor microparticles. When an alternating voltage of the order of 100 V is applied to the electrodes, the LEC emits a bright light. The whole LEC remains stretchable (Fig.1b) and can self-heal when damaged. When pierced by a needle (Fig.1c), the LEC maintained its almost-full light output. This is in marked contrast to a conventional silicone LEC which, when damaged in a similar way, short-circuits, rendering it permanently broken. The HELIOS devices generate more light (> 1,400 cd m^{-2}) at a lower electric field (< 3 V μm^{-1}) than prior LEC devices.

The value of the work presented by Tan and colleagues extends beyond the fields of stretchable optoelectronics and soft robotics described in their article. Smart electroactive transducers, also termed 'artificial muscles', commonly exploit compliant high-permittivity materials to generate useful mechanical work through the generation of electric field-induced Maxwell stresses. The dielectric elastomers actuator (DEA) is an example of such a transducer, most recently demonstrated in a flying microrobot [3]. The ideal elastomer material for DEAs has high relative permittivity (typical values are around 5) and high stretchability (over 500%). The dielectric materials presented in this work have higher relative permittivity (10-27) and good stretchability. This hints at future applications of the presented materials in novel artificial muscles. With such an artificial muscle, the range of potential applications greatly increases. In addition to soft robotics, wearable assist devices for elderly and disabled people may become a reality, as could compliant power suits for factory workers.

The developments presented here are not without limitations and doubtless these will be addressed by the team and also by other scientists. These include the still relatively high voltages (for a 1mm thick device the driving voltage is around 3,000V) and frequencies (typically around 1kHz) that are needed. As with all materials and devices that target soft robotics, the ultimate goal is to integrate their driving electronics and power systems within the soft materials themselves. We are still some way from fully embedded non-silicon soft control and computational systems and fully compliant energy storage systems, be it as soft batteries or as compliant supercapacitors, but recent work suggests that progress is advancing rapidly in these areas [4][5]. It remains to be seen how far these high permittivity soft materials can be developed and the impact they will have in artificial muscle systems. It may be that emerging alternatives such as the electro-fluidic HASEL actuator [6] are adopted as superior technologies. Notwithstanding, the contribution of this work by Tan and colleagues to the fields of compliant optoelectronics and soft robotics is noteworthy.

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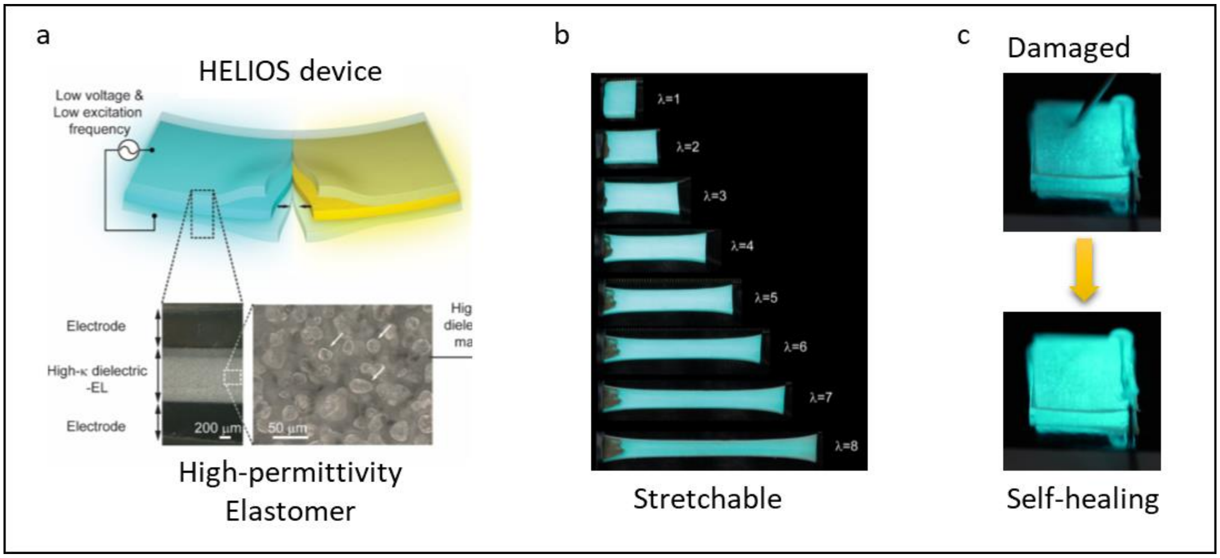

FIG. 1| Highly stretchable, high dielectric, self healing elastomer. a, illustration of the high permittivity material with embedded electroluminescent particles, sandwiched by ionic liquid-doped outer electrodes, forming the tri-layer HELIOS optoelectronic device. **b,** the HELIOS device can be stretched up to eight times its original length without breaking. **c**, the device can be damaged (here, pierced with a needle) and will self-heal, maintaining light output. Adapted from ref.2, SN.

Fig 1a, is adapted from Figure 1 in main text

Fig 1b, is adapted from Extended Data Fig.3c.

Fig 1c, is adapted from Supplementary Fig. Note 2.5